Deconstruction of 5D Gauge-Higgs Model

A Custodial Little Higgs with Fully Radiative Symmetry Breaking

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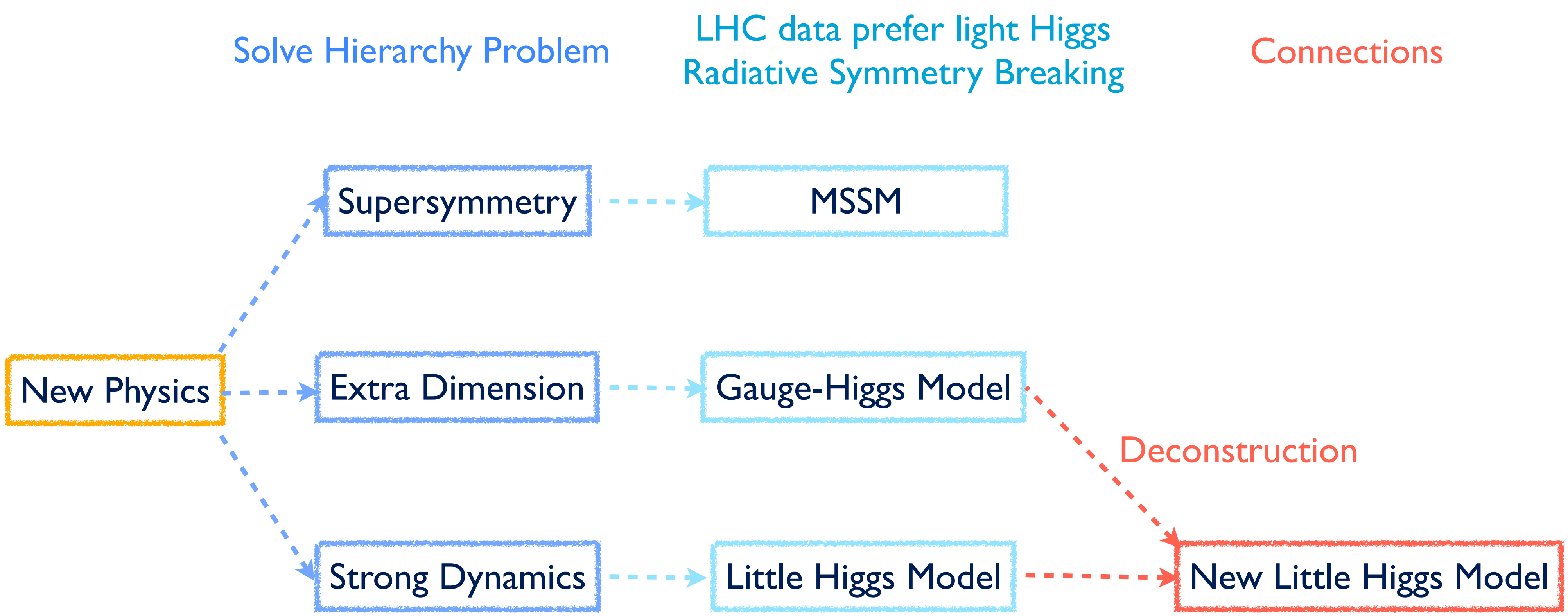
Roshan Foadi, James Laverty, Carl Schmidt, and JHY, JHEP 1006 (2010) 026
Roshan Foadi, Carl Schmidt, and JHY, hep-ph/1109.xxxx

Aug. 30, 2011

The Road Map



Why another Little Higgs Model?

Little Higgs Models

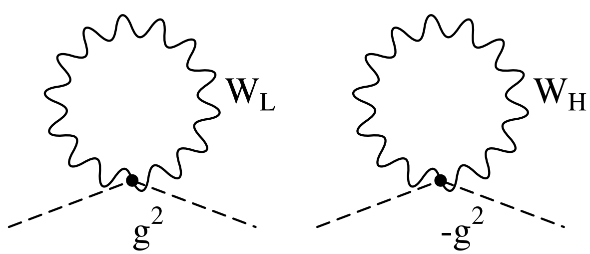
- Brief reviews of Little Higgs (LH):

Collective Symmetry Breaking (CSB): If g_1 = 0 or g_2 = 0, Higgs is Goldstone Boson.

Georgi,
Arkani-Hammed, et.al.

Solve Hierarchy Problem

Quadratic divergence from SM particles in the Higgs loop are cancelled by heavy particles with same spin.



Radiative Symmetry Breaking(RSB)

$$V = m^2|H|^2 + \lambda|H|^4$$

If Higgs potential is purely radiative, expect

$$m^2 \sim \frac{g^4}{16\pi^2} f^2 \,,\ \lambda \sim \frac{g^4}{16\pi^2} \Rightarrow\ v^2 \sim \frac{m^2}{\lambda} \sim f^2$$

Even with heavy top partner contribution:

$$\delta m^2 \sim -\frac{3\lambda_t^2}{16\pi^2} M_T^2$$

Higgs mass still too BIG!

Typically, LH models introduce new operators by hand.

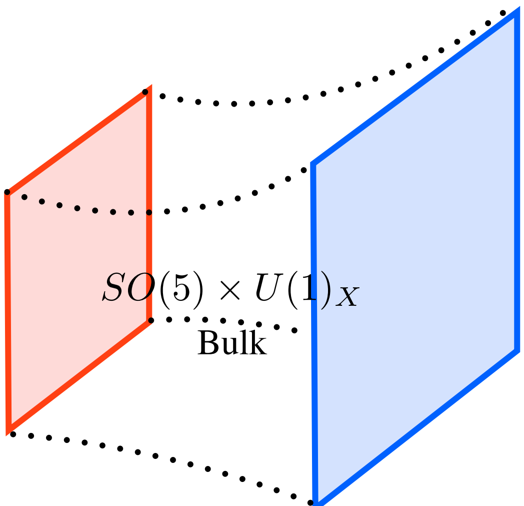
How to generate the light Higgs mass naturally?

Deconstruction of Gauge-Higgs Model

Agashe, Contino, Pomaro

Medina, Shah, Wagner

...



$SU(2)_L \times U(1)_Y$ UV Brane

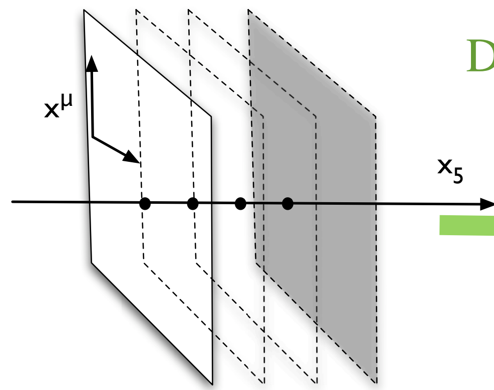
$SU(2)_L \times SU(2)_R \times U(1)_X$ IR Brane

Boundary Conditions

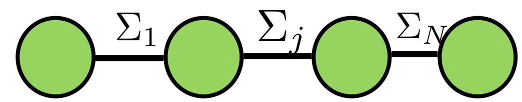
$SU(2)_L \times U(1)_Y$

Fully Radiative Symmetry Breaking

$U(1)_{\rm em}$

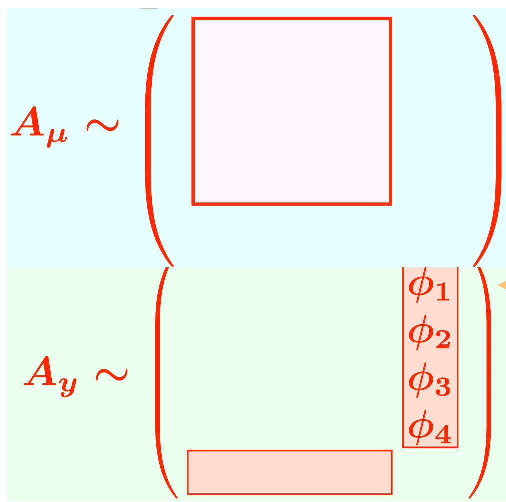


Deconstruction



$$\mathcal{L} = \sum_j \frac{f_j^2}{4} \mathrm{Tr}[(D_\mu \Sigma_j)^\dagger D^\mu \Sigma_j]$$

$$\Sigma_j = e^{i\Pi/f_j}$$



W, Z, γ

AdS/CFT

$$\Pi = \begin{pmatrix} & \begin{pmatrix} H \\ \tilde{H} \end{pmatrix} \\ \begin{pmatrix} H^\dagger & \tilde{H}^\dagger \end{pmatrix} & \end{pmatrix}$$

$$A_y \to A_y + \partial_y \epsilon$$

5-th Gauge transformation

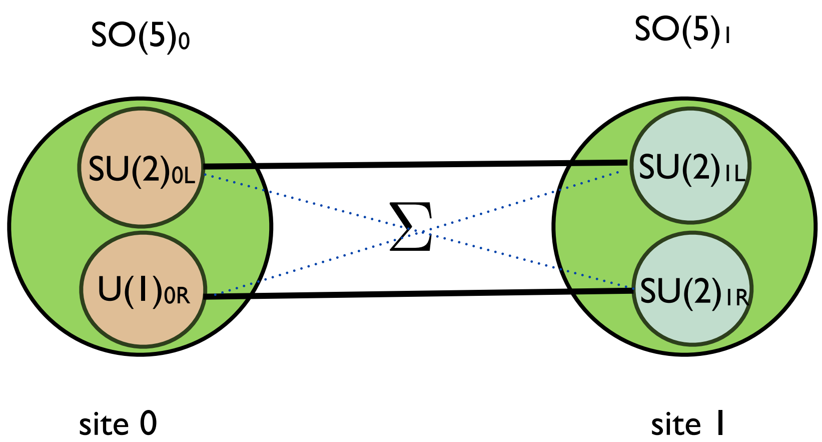
$$h \to h + a$$

Goldstone Shift transformation

A new 4D Little Higgs model with fully radiative symmetry breaking!

A Little Higgs Model

Focus on minimal deconstructed model:



Global symmetry:

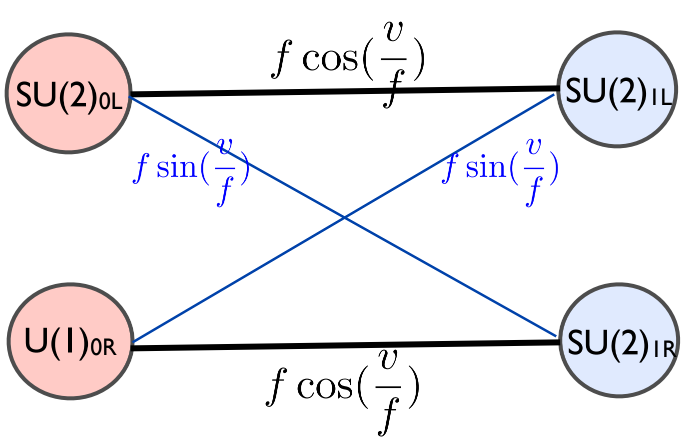
$$SO(5)_0 \times SO(5)_1 \rightarrow SO(5)$$

Gauge symmetry:

$$[SU(2) \times U(1)]_0 \times [SU(2) \times SU(2)]_1$$
$$\rightarrow SU(2)_L \times U(1)_Y$$

Related Models:
Custodial Minimal Moose (Chang, Wacker)
Gauge sector (Barbieri et.al.)

Unfolded Moose
at low energy

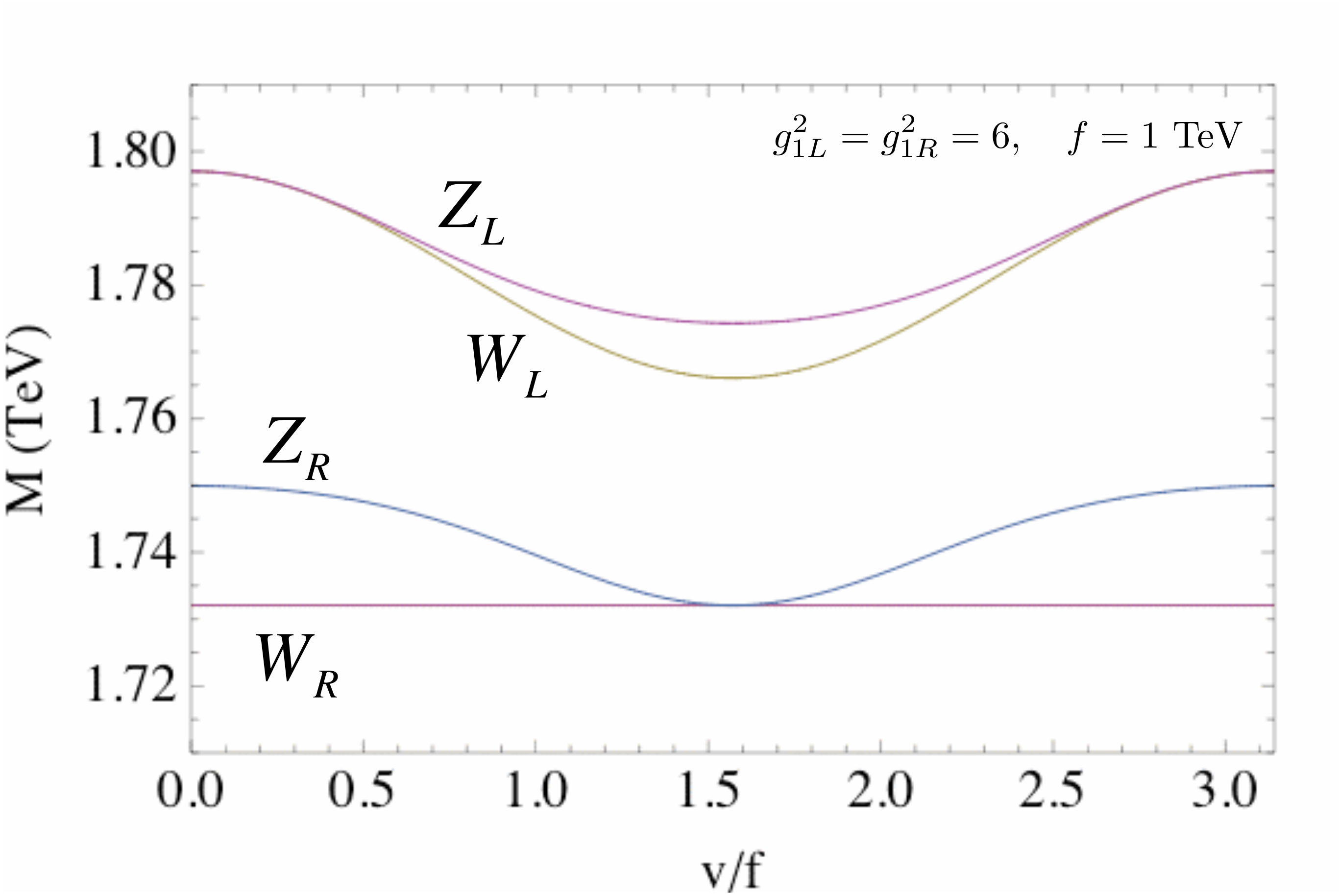


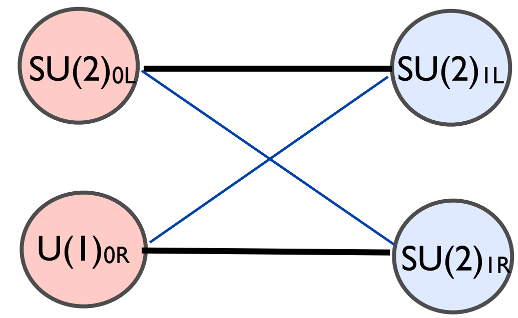
Collective Symmetry Breaking:

If $g_{0L} = g_{0R} = 0$ or $g_{1L} = g_{1R} = 0$(Moose links disappear), Higgs is a Goldstone Boson.

Quadratic divergence vanish at one loop.

Heavy Gauge Bosons





$$
\begin{aligned}
M_{W_L}^2 &= \tfrac{1}{2}\left(g_{0L}^2 + g_{1L}^2\right) f^2 \; + \; \cdots \\
M_{Z_L}^2 &= \tfrac{1}{2}\left(g_{0L}^2 + g_{1L}^2\right) f^2 \; + \; \cdots \\
M_{W_R}^2 &= \tfrac{1}{2} g_{1R}^2 f^2 \; + \; \cdots \\
M_{Z_R}^2 &= \tfrac{1}{2}\left(g_{0R}^2 + g_{1R}^2\right) f^2 \; + \; \cdots
\end{aligned}
$$

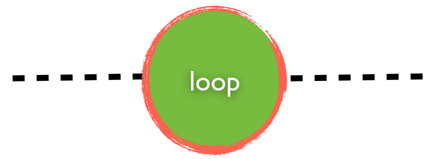
$$
\begin{aligned}
M_W^2 &= g_L^2 f^2 a \; + \; \cdots \\
M_Z^2 &= \left(g_L^2 + g_R^2\right) f^2 a \; + \; \cdots
\end{aligned}
$$

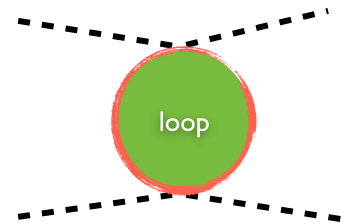
$$a \approx v^2/(4f^2).$$

Higgs boson is the only scalar. All other Goldstone bosons are eaten by gauge bosons.

Higgs Potential

- Higgs potential is generated at loop level:

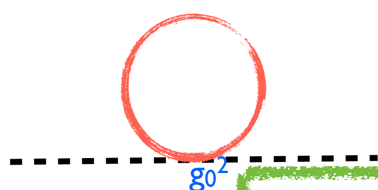
V(H) = 0 + 

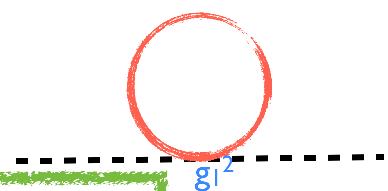
+ 

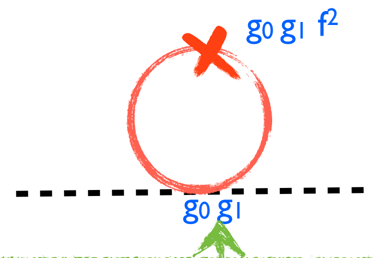
+ ...

Tree level

- Gauge Boson Contribution

m^2 = 

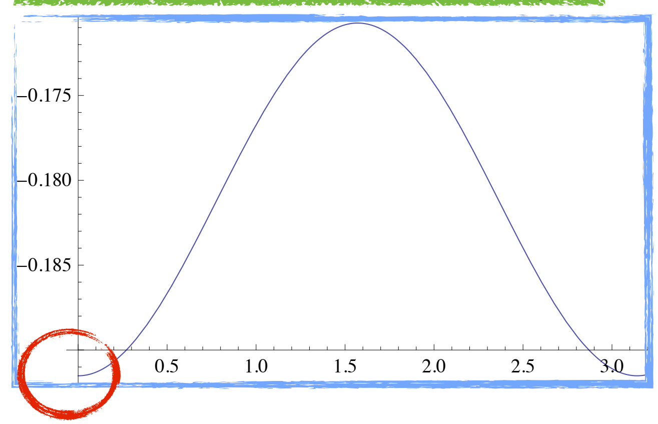
+ 

+ 

No Quadratic div.
CSB

Only Log div.
From Moose links $f\cos(\frac{v}{f})$

$$\simeq 3g_{0L}^2 g_{1L}^2 f^2 \ln \Lambda^2 + g_{0R}^2 g_{1R}^2 f^2 \ln \Lambda^2$$



Positive Loop Corrections to Higgs mass

No spontaneous symmetry breaking!

Fermions and Custodial Symmetry

- Custodial symmetry $SU(2)_L \times SU(2)_R \times U(1)_X$

Agashe, et. al.
Carena, et. al.
Chivukula, et.al.

Third generation Assignment:

$$q_L = \begin{pmatrix} t_L \\ b_L \end{pmatrix} \sim (2,2)_{2/3}, \quad t_R \sim (1,1)_{2/3} \text{ or } (1,3)_{2/3} \quad b_R \sim (1,1)_{-1/3} \text{ or } (1,3)_{-1/3}$$

Avoid large corrections to T parameter, $Zb_L\bar{b}_L$ corrections, and δg_{Rb}.

- Embed into SO(5) Basis:

Carena, Ponton, Santiago, Wagner

$$\begin{aligned}
5_A &= \begin{pmatrix} (\frac{1}{2},\frac{1}{2})_{2/3} & t_L(\frac{1}{2},-\frac{1}{2})_{2/3} \\ (-\frac{1}{2},\frac{1}{2})_{2/3} & b_L(-\frac{1}{2},-\frac{1}{2})_{2/3} \end{pmatrix} \oplus (0,0)_{2/3} \\
5_B &= \begin{pmatrix} (\frac{1}{2},\frac{1}{2})_{2/3} & (\frac{1}{2},-\frac{1}{2})_{2/3} \\ (-\frac{1}{2},\frac{1}{2})_{2/3} & (-\frac{1}{2},-\frac{1}{2})_{2/3} \end{pmatrix} \oplus t_R(0,0)_{2/3} \\
10_C &= (3,1) \oplus b_R(1,3) \oplus (2,2)
\end{aligned}$$

- Gauge Interaction of fermions

Gauge Transformations under $SU(2)_{0L} \times U(1)_{0R}$ only.

Fermions and CSB

- Fermion Contents:

$$\psi_L^A = \begin{pmatrix} Q^u \\ Q^d \\ \chi^y \\ \chi^u \\ u \end{pmatrix}_L^A \qquad \psi_R^A = \begin{pmatrix} \boxed{\begin{matrix} 0 \\ 0 \end{matrix}} \\ \chi^y \\ \chi^u \\ u \end{pmatrix}_R^A \qquad \psi_L^B = \begin{pmatrix} Q^u \\ Q^d \\ \chi^y \\ \chi^u \\ \boxed{0} \end{pmatrix}_L^B \qquad \psi_R^B = \begin{pmatrix} Q^u \\ Q^d \\ \chi^y \\ \chi^u \\ u \end{pmatrix}_R^B$$

Under $SO(5)_0$, $\psi^{A,B} \to U_0 \psi^{A,B}$ (explicitly broken by missing partners)

Under $SO(5)_1$, $\Sigma^\dagger \psi_L^A \to U_1 \Sigma^\dagger \psi_L^A$, $\Sigma^\dagger \psi_R^B \to U_1 \Sigma^\dagger \psi_R^B$

(explicitly broken by spurion field $E^\dagger \Sigma^\dagger \psi_{L(R)}^{A(B)}$)

$$E = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

- Fermion mass terms:

$$\mathcal{L}_{mass} = -\lambda_A f \bar{\psi}^A \psi^A - \lambda_B f \bar{\psi}^B \psi^B - \lambda_1 f \bar{\psi}_L^A \Sigma E E^\dagger \Sigma^\dagger \psi_R^B + \text{h.c.}$$

Break $SO(5)_0$
Preserve $SO(5)_1$

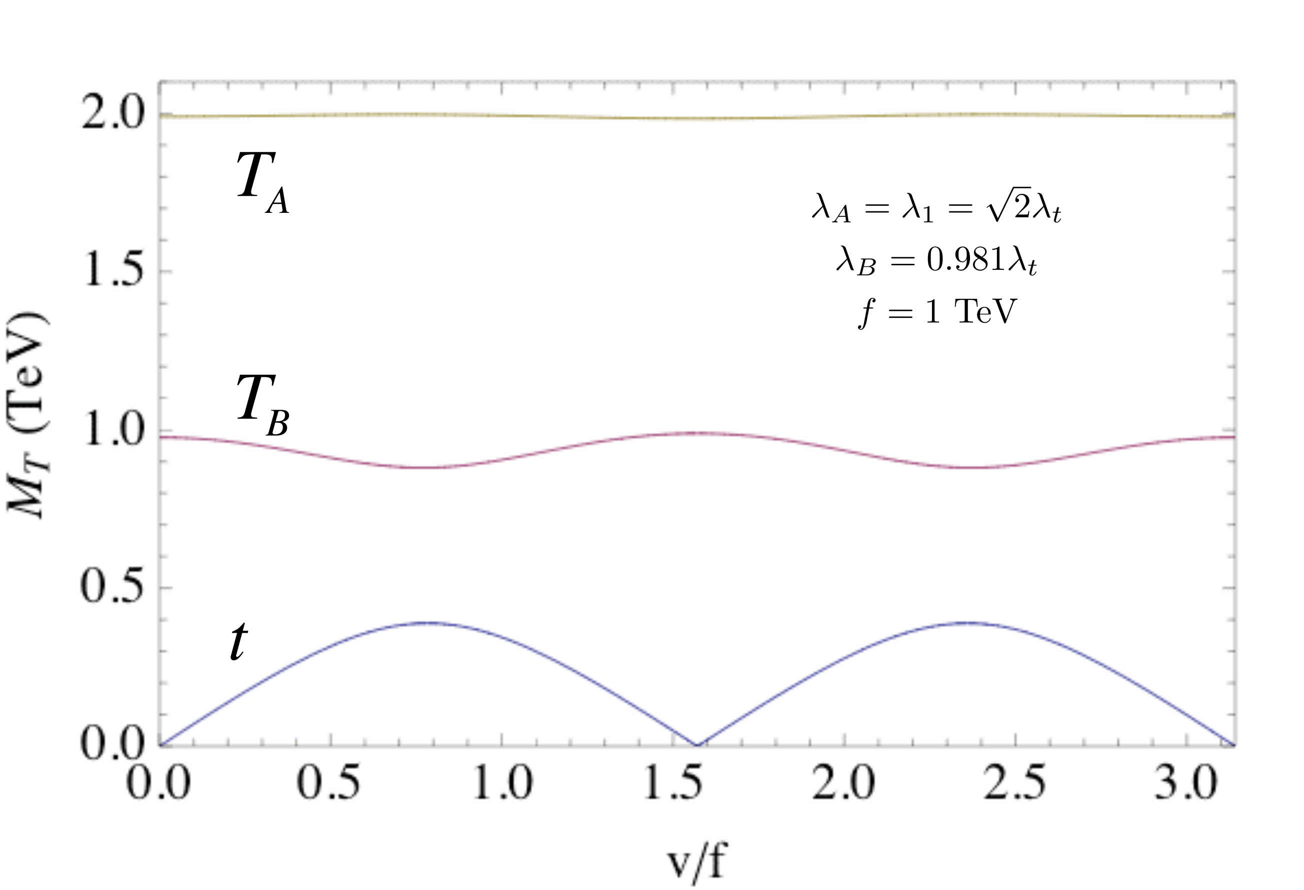
Break $SO(5)_1$
Preserve $SO(5)_0$

Collective Symmetry Breaking (CSB)

Heavy Fermions

Two heavy up-type quarks which mixed with the top quark contribute to the Higgs potential.

All other heavy vector-like fermions are not relevant to radiative symmetry breaking.



$$\psi^A \sim (\chi^u, u)^A \to (T^A, K^A)$$
$$\psi^B \sim (Q^u, \chi^u)^B \to (T^B, K^B)$$

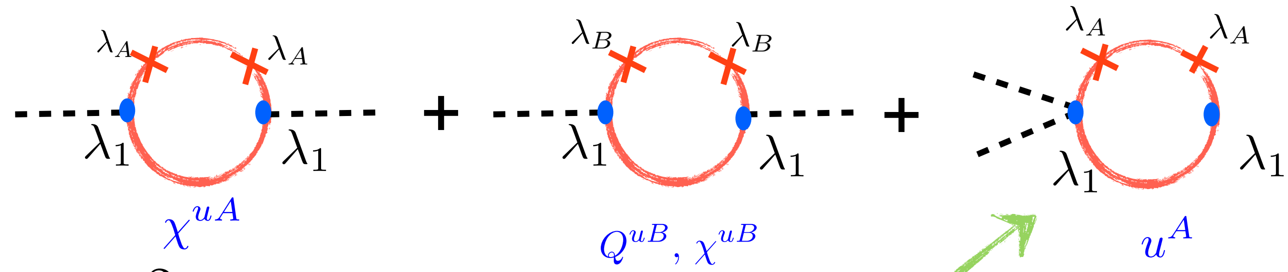
$$M_t^2 = 2\lambda_t^2 f^2 a + \cdots$$
$$M_{T_A}^2 = \left(\lambda_A^2 + \lambda_1^2\right) f^2 + \cdots$$
$$M_{T_B}^2 = \lambda_B^2 f^2 + \cdots ,$$

$$\frac{1}{\lambda_t^2} = \frac{1}{\lambda_1^2} + \frac{1}{\lambda_A^2}$$

Higgs Potential

- Fermion Contribution

$m^2 =$

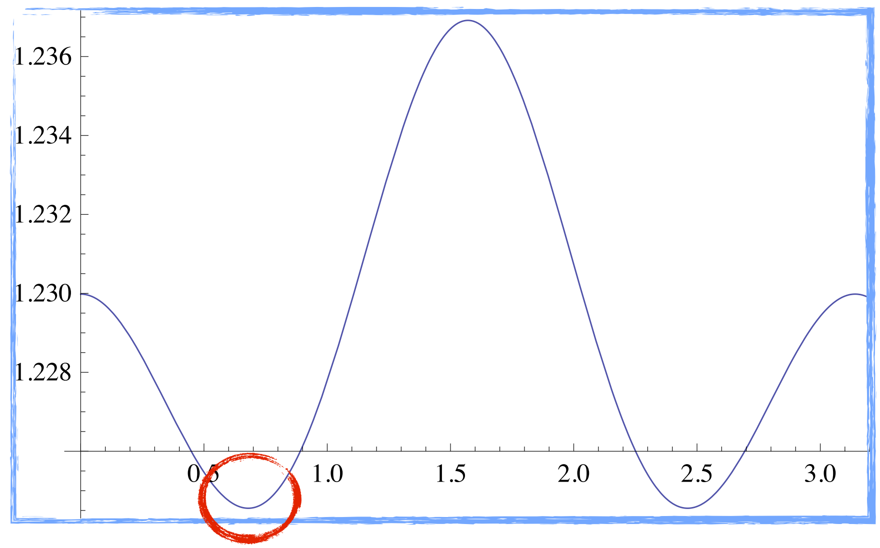


$$\simeq \lambda_1^2 f^4 \frac{\lambda_A^2}{2} \ln \Lambda^2 + \lambda_1^2 f^4 \lambda_B^2 \ln \Lambda^2 - \lambda_1^2 f^4 \lambda_A^2 \ln \Lambda^2$$

This minus sign causes vacuum misalignment and triggers EWSB!

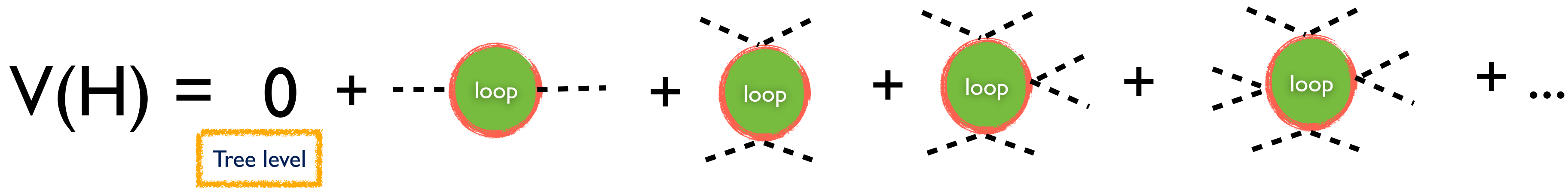
If we turn off λ_B , the Higgs mass recovers the results in littlest Higgs model.

A light Higgs boson mass can be generated naturally through the cancellations on m^2 by two heavy fermion contributions (from 5_A and 5_B).

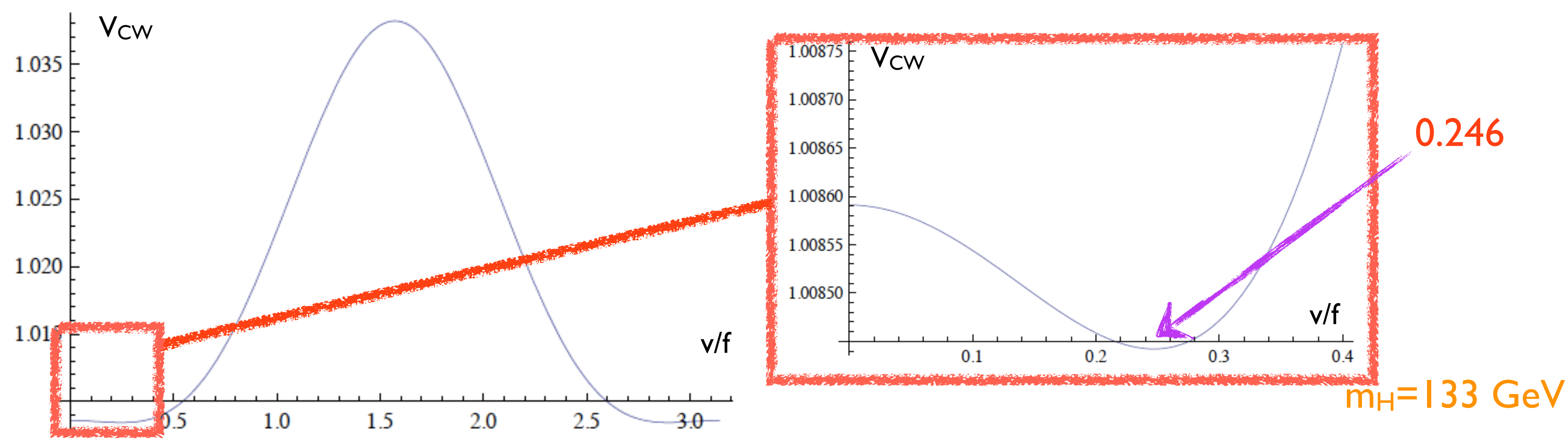


Full Higgs Potential

- The full Coleman-Weinberg Potential is

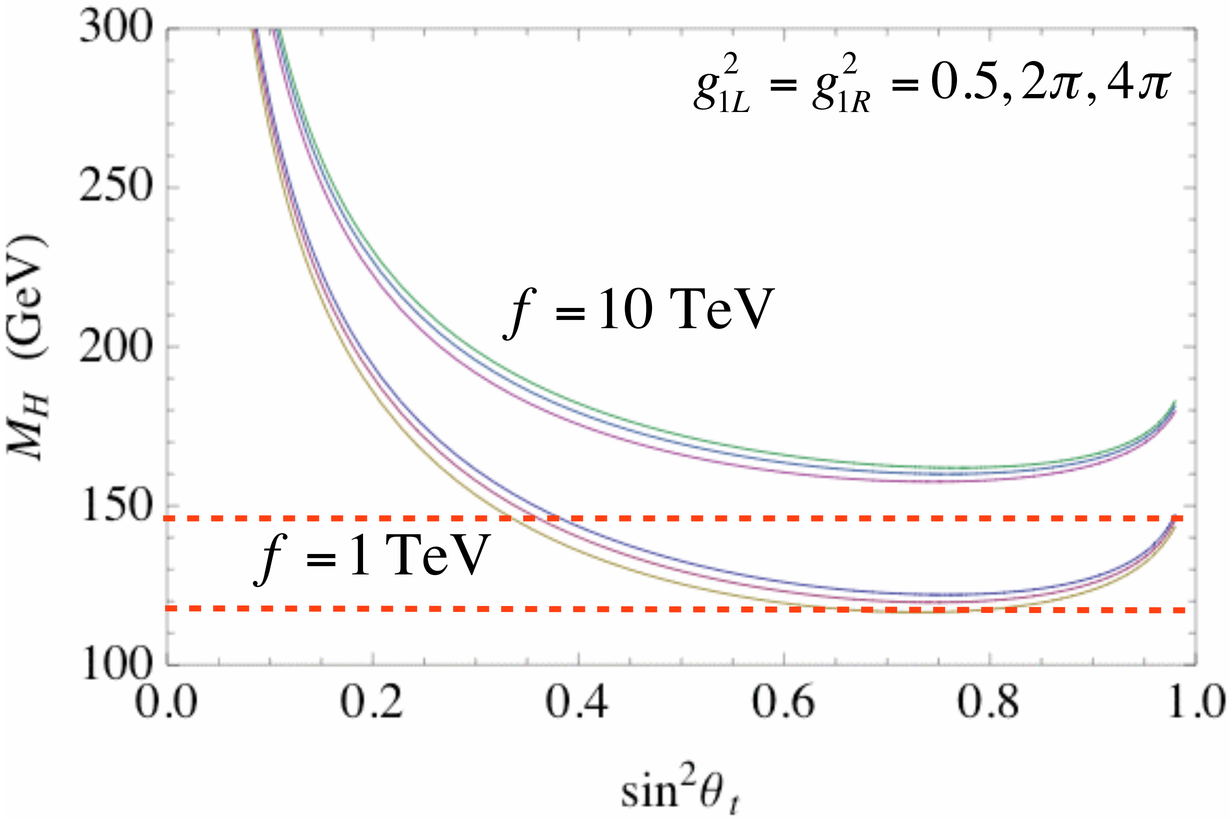


Calculate the one-loop Higgs potential by summing the log terms up to all external legs:



$$v \sim m/\sqrt{\lambda}$$

Light Higgs Boson



Higgs mass is insensitive to gauge couplings

$$\sin\theta_t = \frac{\lambda_1}{\sqrt{\lambda_1^2 + \lambda_A^2}}$$

$\boxed{\text{Higgs boson is typically light.}}$

λ and v are correlated each other.
Value of λ is constraint by correct v.

Why is Higgs mass solution typically light?

$$M_H^2 \approx 2\lambda v^2 \quad \text{with} \quad \lambda \approx \underbrace{\frac{3\lambda_t^4}{4\pi^2}\left\{\frac{1}{4}\ln\frac{M_{T_A}^2}{M_t^2}\right.}_{\text{Compare to SUSY}} + \left. F\left(\sin\theta_t, M_{T_A}^2/M_{T_B}^2\right)\right\}$$

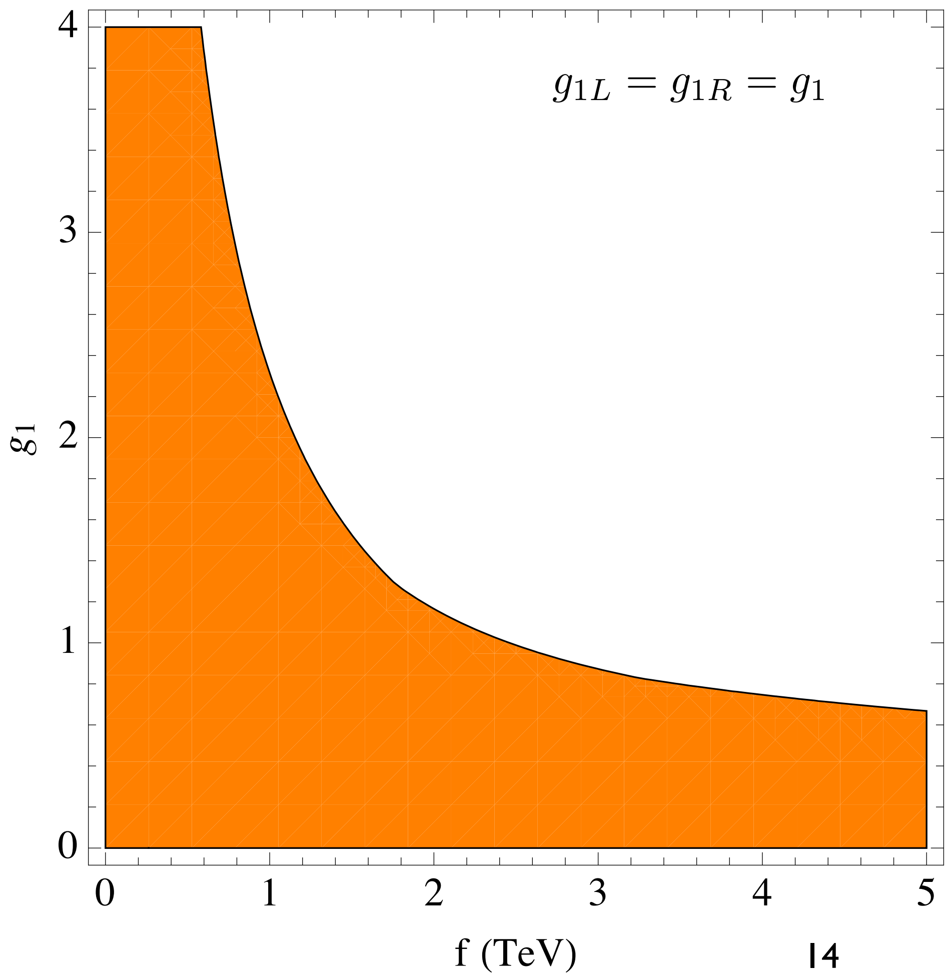
Electroweak Precision Tests

- The model parameters:

  gauge sector: g_L, g_R, g_{1L}, g_{1R} top sector: $\lambda_t, \sin\theta_t, \lambda_B$, scale: f, v

- Bounds on universal electroweak parameters

Barbieri, et.al.



$$\Delta\hat{S}_{\text{tree}} = a\left(\frac{g_L^2}{g_{1L}^2} + \frac{g_L^2}{g_{1R}^2}\right)$$

$$\Delta\hat{T}_{\text{tree}} = 0$$ custodial symmetry

$$\Delta Y_{\text{tree}} = a\left(\frac{2g_L^2 g_R^2}{g_{1R}^4}\right)$$

$$\Delta W_{\text{tree}} = a\left(\frac{2g_L^4}{g_{1L}^4}\right) .$$

$$g_R = g', \quad a \simeq v^2/4f^2$$

One loop corrections to the S,T parameters and Z-b-bbar couplings are also calculated to further put bounds on top sectors.

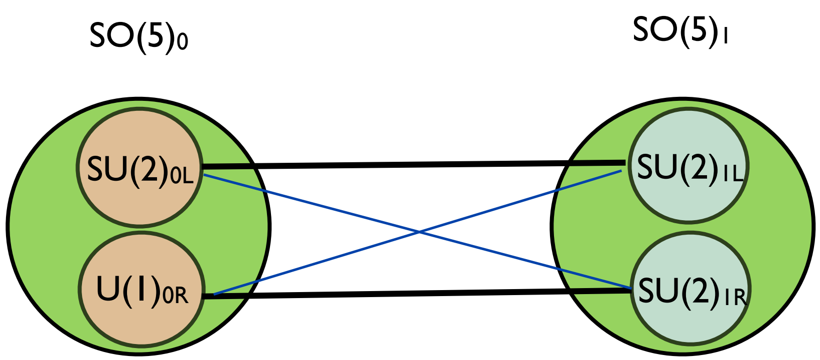
Summary

5D Gauge-Higgs Model

Deconstruction

UV completion

Custodial Little Higgs Model



The only scalar: Higgs boson

AdS/CFT:
5th Gauge Boson(zero mode) <> PG Boson
(Collective Symmetry Breaking)

The Higgs boson masses are typically light.

New fermions: two heavy Tops

Two heavy top quarks to have fully radiative symmetry breaking naturally.

Z-b-bbar are protected by custodial symmetry.

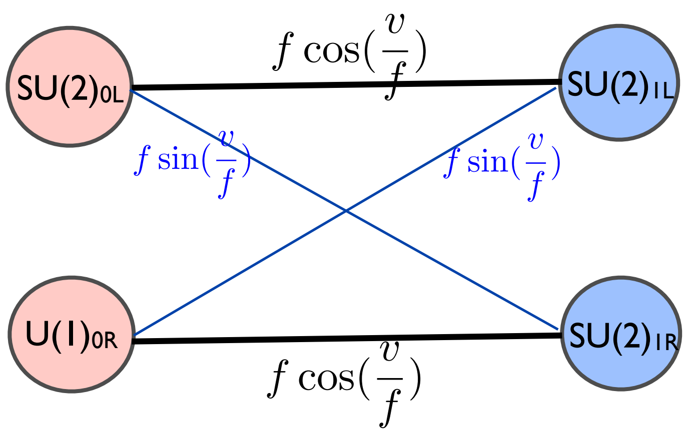
Parameter Constraints from EWPTs and Higgs mass exclusion limits

The END

Thank You

Backup Slides

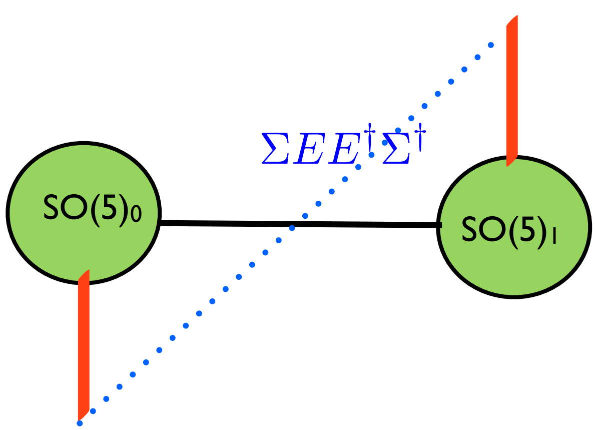
Moose Diagram and Mass Matrices



$$\frac{f^2}{2}\begin{pmatrix} g_{0L}^2 & -(1-a)g_{0L}g_{1L} & -ag_{0L}g_{1R} & 0 \\ -(1-a)g_{0L}g_{1L} & g_{1L}^2 & 0 & -ag_{1L}g_{0R} \\ -ag_{0L}g_{1R} & 0 & g_{1R}^2 & -(1-a)g_{1R}g_{0R} \\ 0 & -ag_{1L}g_{0R} & -(1-a)g_{1R}g_{0R} & g_{0R}^2 \end{pmatrix}$$

$$a = \sin^2\left(\frac{|H|}{\sqrt{2}f}\right)$$

Fermion Links:

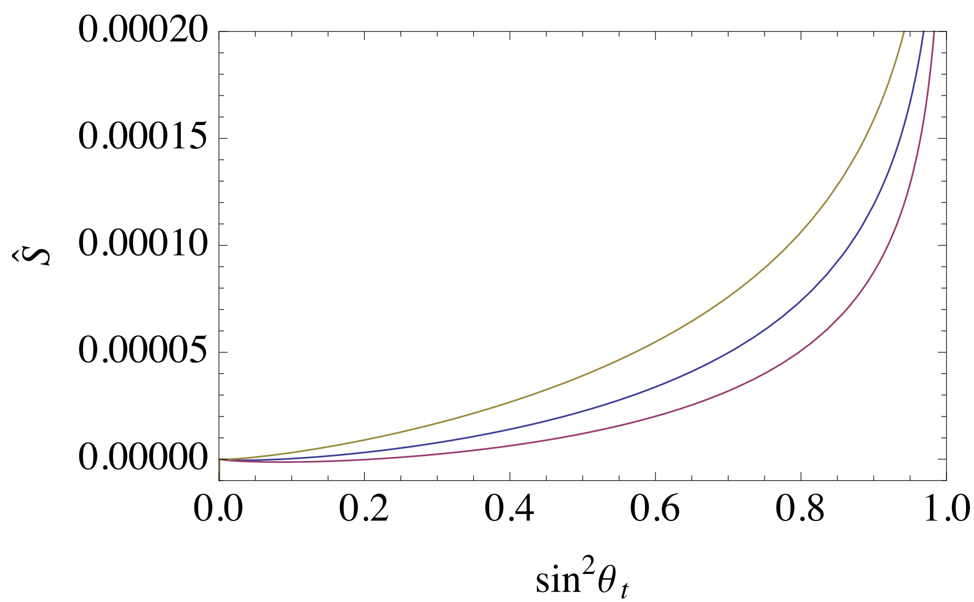


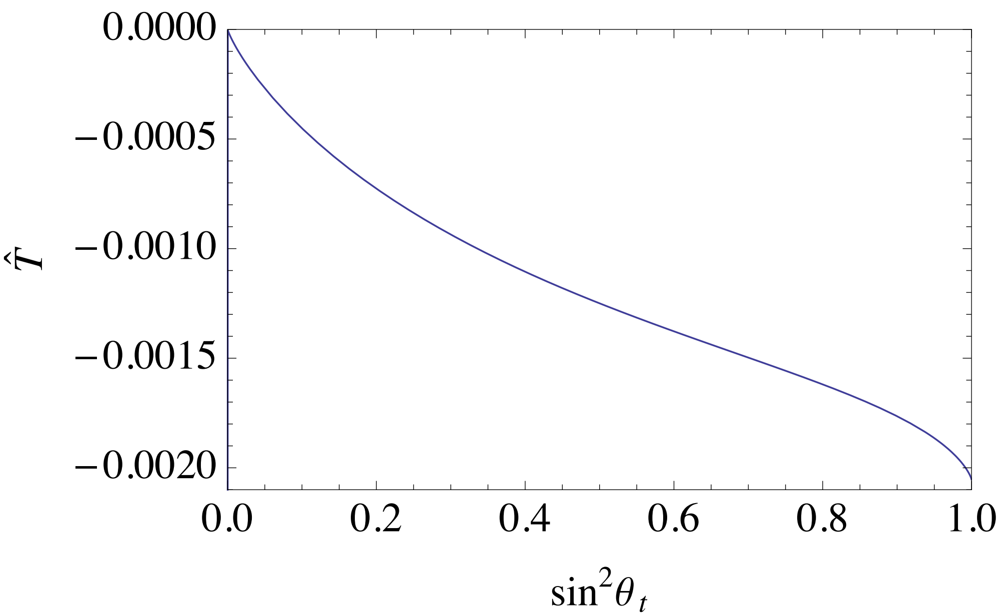
$$\begin{pmatrix} \frac{s^2}{2} & 0 & 0 & \frac{s^2}{2} & \frac{isc}{\sqrt{2}} \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \frac{s^2}{2} & 0 & 0 & \frac{s^2}{2} & \frac{isc}{\sqrt{2}} \\ -\frac{isc}{\sqrt{2}} & 0 & 0 & -\frac{isc}{\sqrt{2}} & 1-s^2 \end{pmatrix}$$

$$\Sigma E E^\dagger \Sigma^\dagger (M_A^2 + M_B^2)$$

Electroweak Constraints (Loop Level)

fermion loop contributions to S and T (bounds on parameters in the fermion sector)





Zbb one-loop corrections

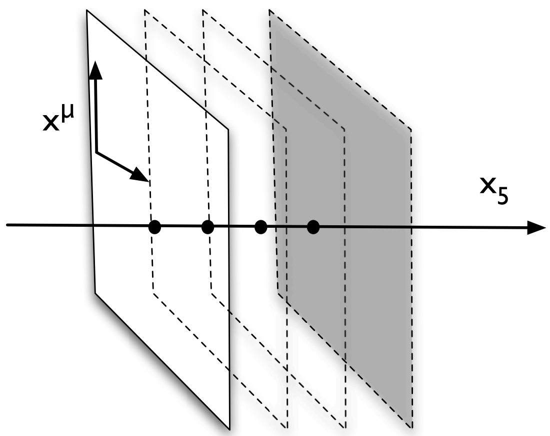
$$\Delta\mathcal{L}_{bbZ}^{\text{renorm}} = \frac{e}{\sin 2\theta}\bar{b}_L\gamma_\mu b_L Z^\mu \; a\left[\hat{\epsilon}_1 + \left(\frac{g_L^2}{g_{0L}^2} - \frac{g_L^2}{g_{1L}^2} - \frac{g_R^2}{g_{0R}^2} + \frac{g_R^2}{g_{1R}^2}\right)\hat{\epsilon}_2\right]$$

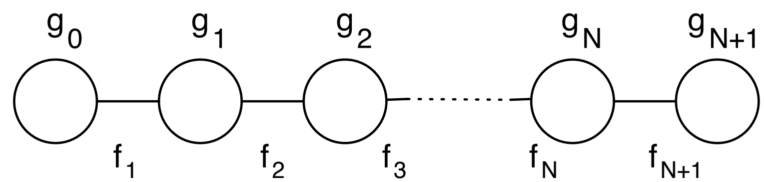
$$\hat{\epsilon}_1 = -\frac{4\lambda_t^2}{(4\pi)^2}\left[1 - \frac{1}{2}\frac{\lambda_t^2}{\lambda_A^2} - \frac{3}{2}\frac{\lambda_t^4}{\lambda_1^2\lambda_A^2} + \left(\frac{\lambda_t^4}{\lambda_1^2\lambda_A^2} - \frac{3}{4}\frac{\lambda_t^2}{\lambda_A^2}\right)\ln\frac{m_{T_A}^2}{m_t^2}\right],$$

$$\hat{\epsilon}_2 = \hat{\kappa}_A + \frac{\lambda_1^2}{4(4\pi)^2}\left(\frac{3}{2} - \ln\frac{m_{T_A}^2}{\mu^2}\right) + \frac{\lambda_t^2}{4(4\pi)^2}\ln\frac{m_{T_A}^2}{m_t^2}.$$

Moose Notation

From Chivukula's slides





$$\mathcal{S}_5 = \int d^4x\, dy \left[-\frac{1}{2\, g^2 \kappa^2(y)} \mathrm{tr}(F_{\mu\nu}F^{\mu\nu}) + \frac{f^2 h^2(y)}{4} \mathrm{tr}\,(F_{\mu y}F^{\mu y}) \right]$$

$$\mathcal{S} = -\int d^4x \sum_{j=0}^{N+1} \frac{1}{2g_j^2} \mathrm{tr}\,(F^j_{\mu\nu}F^{j\mu\nu}) + \int d^4x \sum_{j=1}^{N+1} \frac{f_j^2}{4} \mathrm{tr}\left((D_\mu U_j)^\dagger (D^\mu U_j)\right)$$

$$D_\mu U_j = \partial_\mu U_j - i A^{j-1}_\mu U_j + i U_j A^j_\mu$$

Example

$SU(2)_W \times U(1)_B \longrightarrow U(1)$ $\longleftrightarrow$